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LUNAR LANDING AND SITE SELECTION STUDY

PHASE I, PRESELECTED LANDING SITE

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
Houston, Texas

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PHASE I, PRESELECTED LANDING SITE

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TABLE OF CONTENTS

LIST OF FIGURES

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SUMMARY

The study consists of two phases - Phase I, reported in this paper, is a study of candidate trajectories and the LEM visual field. Phase II, utilizing Phase I results, is to be a study of site selection capabilities in a simulated lunar terrain, and trajectory utilization as a function of brightness level and vision restriction.

Phase I was conducted to investigate LEM landing trajectories, from 1,000 feet altitude to the surface, with respect to the ability of a pilot to land at a preselected site under restricted vision and reduced brightness levels.

Recognition of a high contrast target was possible from 5,000 feet slant range and 1,000 feet altitude in the LEM "C" configuration for all of the trajectories investigated. Protuberances and depressions, when viewed normally, were discernible by contrast, not slope. A series of protuberances viewed in excess of 500 feet slant range appeared as a common slope or mound.

The helicopter appears to provide a suitable means of studying LEM vision and lighting problems.

Neutral density filters are suitable light attenuation devices provided blue gelatin filters are not used in combination, and light leakage problems are solved.

Because of the potential difficulty and attendant problems in site selection, and to achieve full advantage of past piloting experience, the handling characteristics for the LEM should be equivalent to or better than those of existing production helicopters.

INTRODUCTION

Similarity of LEM trajectories to the flight capabilities of rotary wing aircraft during the landing phase suggested the use of a helicopter for a study of LEM landing vision requirements. A two-place helicopter, having maximum forward vision, was chosen. Predicted LEM flight profiles were resolved into flight profiles for the helicopter, thus simulating in flight some of the problems that may be experienced by the LEM crew. This study represents an initial investigation of vision requirements. Future static simulations and flight tests are expected to give more conclusive results.

The objectives of Phase I, reported herein and Phase II, to be conducted at a later date are listed below:

Phase I (Conducted at a conventional airport)

1. Evaluate helicopter simulated LEM trajectories from 1,000 feet altitude to touchdown.

2. Assess the visual field required to land on a preselected site.

Phase II (To be conducted over simulated lunar terrain)

3. Assess the visual field required to identify and land at simulated lunar landing sites.

4. Evaluate visual problems under the reduced lighting of earthshine.

5. Evaluate illumination levels required to identify a satisfactory lunar landing site.

FACILITIES AND EQUIPMENT

Site Selection

An area 200 feet wide and 7,500 feet long paralleling runway 4R-22L at Ellington Air Force Base was utilized. This area was marked with high visibility panels. The starting point was marked with a "V", with the point of the "V" in the direction of the target touchdown area. The arms of the "V" were four feet wide and twelve feet long with one arm colored red and the opposite white. The 400 foot-altitude ground reference marker was a forest green canvas, 6 feet wide and 12 feet long placed in a white sand area. In the center was a white arrow, 4 feet long and pointing toward the touchdown target. The touchdown target was an open square, 12 feet by 12 feet with alternating red and white sides. In the center was a smaller square (4 feet by 4 feet, red and white) and marked with a center "X" used for miss distance measurement reference. These panels were chosen to provide a high degree of target contrast with respect to the background in order to be able to better assess the visual field of the LEM window and determine trajectory suitability. Target to background contrast ratio was .70.

Aircraft Modification

The right window of a Bell 47G helicopter was modified to simulate the "C" configuration of the LEM window. This was accomplished by masking the canopy of the helicopter with acrylic plexiglas. Figure 1 is a photograph showing the window configuration as used on the helicopter. Figure 2 is a graphic presentation of the LEM "C" configuration superimposed over the actual window configuration used in this study. The pilot wore goggles with Eastman Kodak Wratten #47 blue filters. This filter, in combination with orange plexiglas, eliminated all visible light from the pilot's eyes, but allowed light at the blue end of the visual spectrum to enter the eyes from window areas not covered with orange plexiglas.

Two 16 mm movie cameras were mounted on the helicopter. One camera was mounted inside the aircraft on the aft cabin firewall, above and between the two pilots. This camera recorded flight instruments including altitude, air speed, and elapsed time during descent. The second camera was mounted on the horizontal landing strut support and recorded the target area during each approach. A third, 35 mm serial, hand-held camera was used for recording the pilot's visual field through the "C" window during representative approaches. This camera took one exposure per second from the start of the approach to touchdown. Figure 3 shows a serial view of a typical autorotation trajectory, taken with the 35 mm camera, as seen by the pilot through the "C" window without light attenuating filters. Also installed in the aircraft was a tape recorder for pilot comments during the flight trajectory.

Trajectories

Six different LEM landing trajectories from 1,000 feet altitude to touchdown were used (fig. 4). Trajectory I was a vertical descent from 1,000 feet to 100 feet followed by transition to level flight and a direct approach to the target area. Trajectories II, III, and IV combined vertical and horizontal descent vectors for a normal straight-in approach from 1,000 feet altitude to touchdown. Trajectories V and VI utilized a vertical descent from 1,000 feet to 400 feet altitude and translation to a straight-in approach to touchdown.

Lighting

Optical filters were chosen to simulate lunar surface brightness under full earthshine conditions. In order to closely simulate this condition, a pair of goggles fitted with Bausch and Lomb #5 neutral density filters were worn by the pilots. No attempt was made to consider all the variables, that is, photometric function, albedo extremes, et cetera, affecting the light conditions expected on the lunar surface. A general reflected light reduction to less than .113-foot lamberts was accomplished.

The goggles were fitted with two filters: the Wratten #47 blue filter with a total spectrum transmittance of 1.2 percent and the Bausch and Lomb #5 N.D., with a total spectrum transmittance of 2.9 percent. This results in a light reduction to 0.0348 percent. There was an additional 10 percent loss of transmitted light through the aircraft window providing a total reduction to .0313 percent of ambient light. Before and after completion of each flight, light transmittance readings were taken through the filters. These readings were taken with the photo cell of the light meter pointing 30 degrees below the horizontal. Figure 5 is a reproduction of figure 3 showing a comparison between the pilot's normal vision and that seen when wearing the goggles. Table I shows the average transmitted light through the goggles for each flight day. Due to the intentional high contrast of target to background, lunar contrast ratio was not accurately simulated. Background brightness levels were generally at or less than expected lunar maria values. In order to determine trajectory suitability and visual field adequacy, a contrast ratio higher than expected lunar contrast between target and background was necessary.

Flight Crew

Three qualified helicopter pilots were used. Prior to the actual program and during modification of the helicopter the aircraft was available for pilot familiarization. During this period, practice approaches and landings were made by all pilots in order to simulate the LEM profile as closely as possible within the flight limitations of the helicopter.

PROCEDURES

Each pilot performed three to five practice approaches and landings per trajectory. Upon completion of the practice approaches, the pilot attempted to land on the preselected site. Four trials of each trajectory were flown.

The pilot controlled the helicopter under reduced illumination and restricted window configuration from the initial 1,000 feet altitude starting point to the landing of the helicopter. A safety pilot with unrestricted vision was on board. The exterior camera recorded aircraft approach, and the interior camera recorded the flight instruments. The hand-held serial camera was used during practice runs to record the visual field and landing site through the window for each representative trajectory. Pilot comments were recorded during the flight.

RESULTS

Trajectory V was not flown due to flight safety considerations. Trajectory III was possible only under certain wind conditions: Any crosswind component or low magnitude tail wind caused difficulty in duplicating the 25 degree approach angle. The pilots demonstrated a high degree of repeatability on the remaining trajectories.

The brightness levels simulated are shown in table I. The lunar photometric properties were not considered for simulation in this phase of the program. However, table I shows that on flight days 8 and 12, the simulated brightness levels are those that would be expected on the lunar surface during 3/4 and full earthshine with viewing angles of 76 degrees and 70 degrees, respectively. Column 2 represents the brightness level achieved and Column 3 the comparable brightness levels that are within the expected lunar range. Column 4 shows the lunar conditions necessary to yield the simulated values. On nine of the twelve flight days, theoretical lunar conditions were approximated.

Because a blue filter was used in combination with the neutral density filter, visual perception was in the blue spectrum. This condition darkened the shadows and gave terrain a flat appearance.

In general, no visual problems existed with the "C" window configuration for any of the trajectories except trajectory I, where the target would drop out of view at approximately 200 feet altitude during the vertical descent phase of the trajectory.

No problems existed in recognition of the landing site from approximately 5,000 feet slant range at 1,000 feet altitude in the ranges of visibility studied. Disorientation occurred when the lower window was used without the upper window due to lack of horizon, known objects, or landmarks in the field of view.

Because the site had a high degree of contrast with respect to the background, numerous cues were available for locating its general area of placement. The pilots, in viewing dirt mounds, buildings, and contrasting level patches on the surface from various altitudes, made the following observations:

1. Dirt mounds and crater type excavations when viewed normal to the surface appear level and are discernible from surrounding areas by contrast levels only, when viewed from a slant range in excess of 400-500 feet, appear as a common slope.

2. Contrasting ground patches can be detected. However, the degree of contrast detectable is yet to be defined.

3. Two pilots experienced some difficulty in accurate judgment of altitude during the period of final flare. The difficulty appeared to be a function of unfamiliarity with the neutral density filter goggles, the flare and landing task becoming easier and requiring less time as the number of trials increased.

CONCLUSIONS

No visual problems existed with the "C" window configuration during any of the approach trajectories. It appears, however, that it would be desirable to have the upper window closer to the pilot, especially during the final flare maneuver. The use of the lower window will be necessary if a vehicle strut must be precisely placed over a given point on the surface. A single window placed closer to the pilot could provide the equivalent or better visibility with less window weight.

The illumination levels simulated were those which are expected on the lunar surface under full and 3/4 earthshine conditions for normal viewing in a maria area. No photometric properties were considered in planning this phase of the program. The high visibility panels and the earth background had a contrast ratio of .70. The contrast ratio was computed by dividing the difference of the light reflected by the target and background by the light reflected by the target. The contrast ratio of the lunar surface is reported in various publications as ranging from 0.30-0.58. A high degree of contrast was desirable for this phase in order to give the best visual perception of the landing target to the subjects under the reduced lighting conditions. This was necessary in order to be able to assess the visual field envelope of the window configuration and suitability of the trajectories being studied.

Of the trajectories investigated, trajectory VI appears promising when the pilot has selected a landing site prior to initiating a descent. According to pilot comments, Trajectory VI permitted an expeditious, comfortable, and convenient approach angle to a known target.

The profile of trajectory I presents an advantage when the site cannot be selected at 1,000 feet altitude due to low brightness levels, requiring a lower altitude to find a suitable landing site. At the lower altitude a reduction in translational velocity may be required.

Neutral density filters are satisfactory as light attenuation devices provided they are used independently of other filters, and light leakage problems are solved.

The trajectories investigated appear to represent the range of LEM vehicle utilization, and the helicopter is suitable for simulation of these trajectories.

The results of this phase indicate the need for an extensive training program at brightness levels expected on the lunar surface. There are additional levels of brightness (less than those simulated in Phase I) which must be investigated in an area of homogeneous terrain where no preselected landing sites exist and no recognizable cues are available for definition of slope and boulder sizes. The albedo of this area should approximate that of the lunar surface.

The following phase of this study will be conducted on the lava flow at Pisgah Crater, California.

Because of the potential difficulty and attendant problems in site selection, and to achieve full advantage of past piloting experience, the handling characteristics for the LEM should be equivalent to or better than those of existing production helicopters.

TABLE I.- TABULATION OF BRIGHTNESS LEVELS

Flight day	Measured reflected light through filters at test site (foot lamberts)	Lunar brightness levels simulated (foot lamberts)	Theoretical lunar conditions
1	0.8	none	Higher than would be expected
2	0.075	0.075	Full earth, 6.5 percent albedo, normal viewing
3	0.067	0.067	Full earth, 5.0 percent albedo, normal viewing
4	0.8	none	Higher than would be expected
5	0.041	0.041	3/4 earth, 6.5 percent albedo, normal viewing
6	0.084	0.084	Full earth, 6.5 percent albedo, normal viewing
7	0.185	none	Slightly higher than would be expected
8	0.0147	0.0147	3/4 earth, 9 percent albedo, 76° viewing angle
9	0.051	0.051	3/4 earth, 7.5 percent albedo, normal viewing
10	0.04	0.04	3/4 earth, 6.5 percent albedo, normal viewing
11	0.041	0.041	3/4 earth, 6.5 percent albedo, normal viewing
12	0.0185	0.0185	Full earth, 5.0 percent albedo, 70° viewing angle

NOTE: Viewing angle is measured from the local vertical to the observer's line of sight.

Figure 1.- View of helicopter showing the windshield modified to the LEM configuration "C".

WINDOW CONFIGURATION USED IN SIMULATION

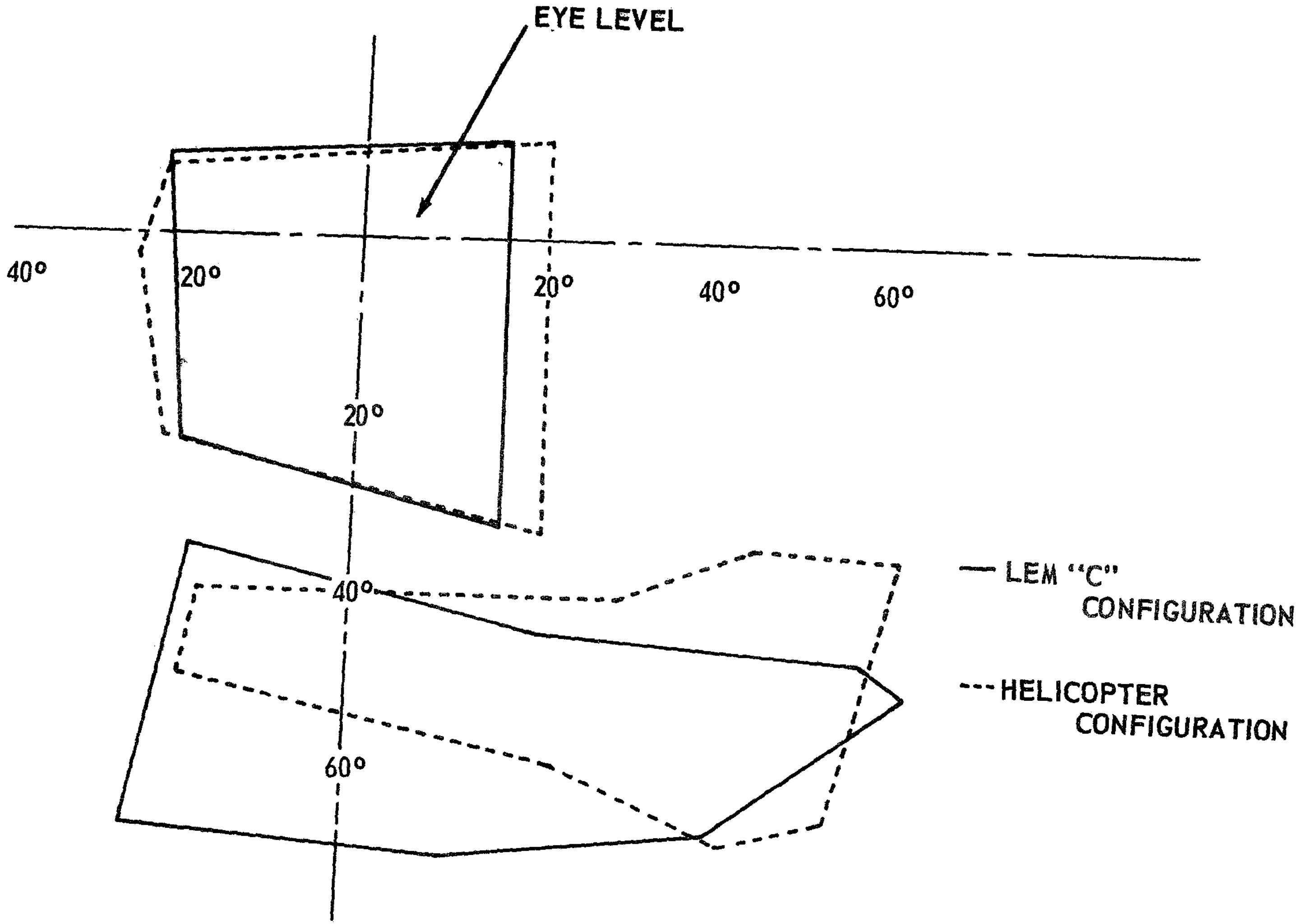

Figure 2 - Comparative field of view for helicopter and LEM "C" window configuration

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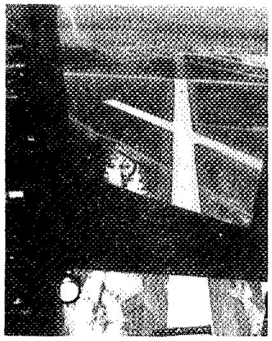
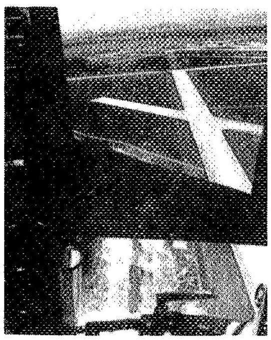


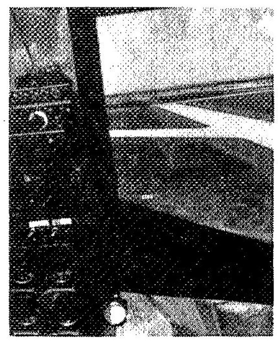
START
930 ft-alt

46 SEC
250 ft-alt

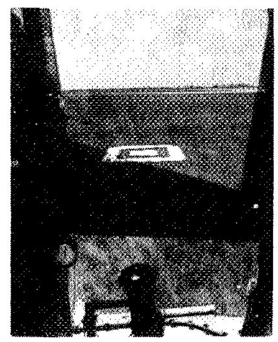
69 SEC
20 ft - alt



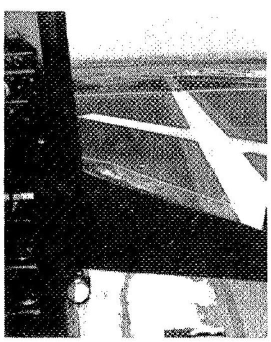
20 SEC
620 ft - alt



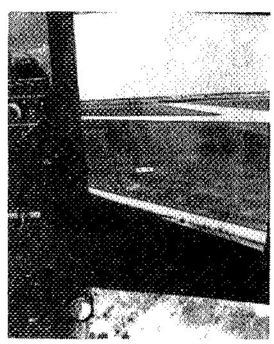
54 SEC
180 ft-alt



71 SEC
15 ft - alt

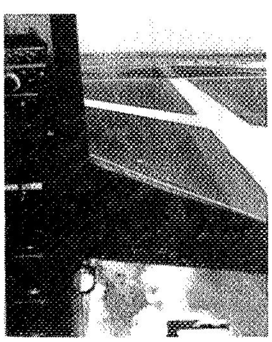


31 SEC
440 ft - alt

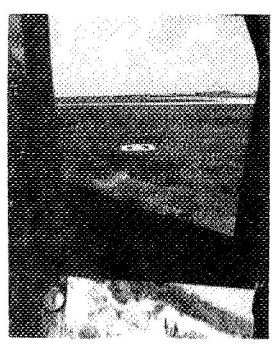


60 SEC
90 ft - alt

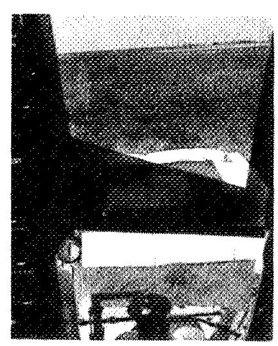
73 SEC
10 ft - alt



41 SEC
300 ft - alt



66 SEC
30 ft - alt



77 SEC
5 ft - alt

Figure 3 - A typical autorotation trajectory - upper window view of landing target

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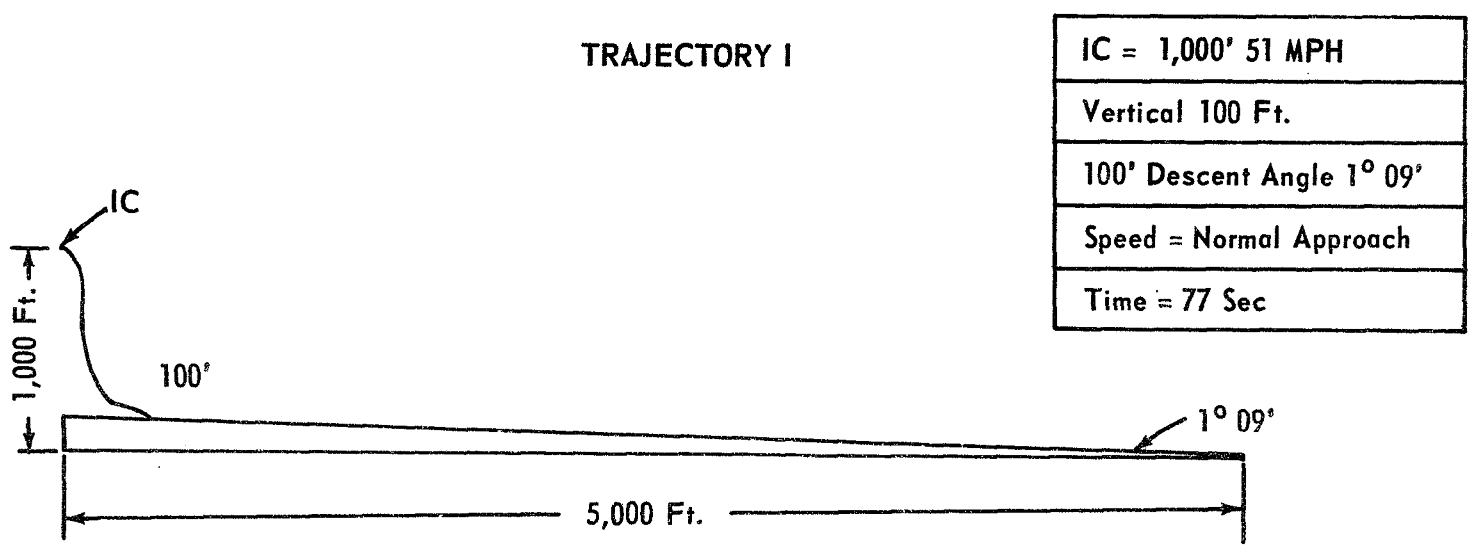

Figure 4 - Trajectories

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TRAJECTORY II

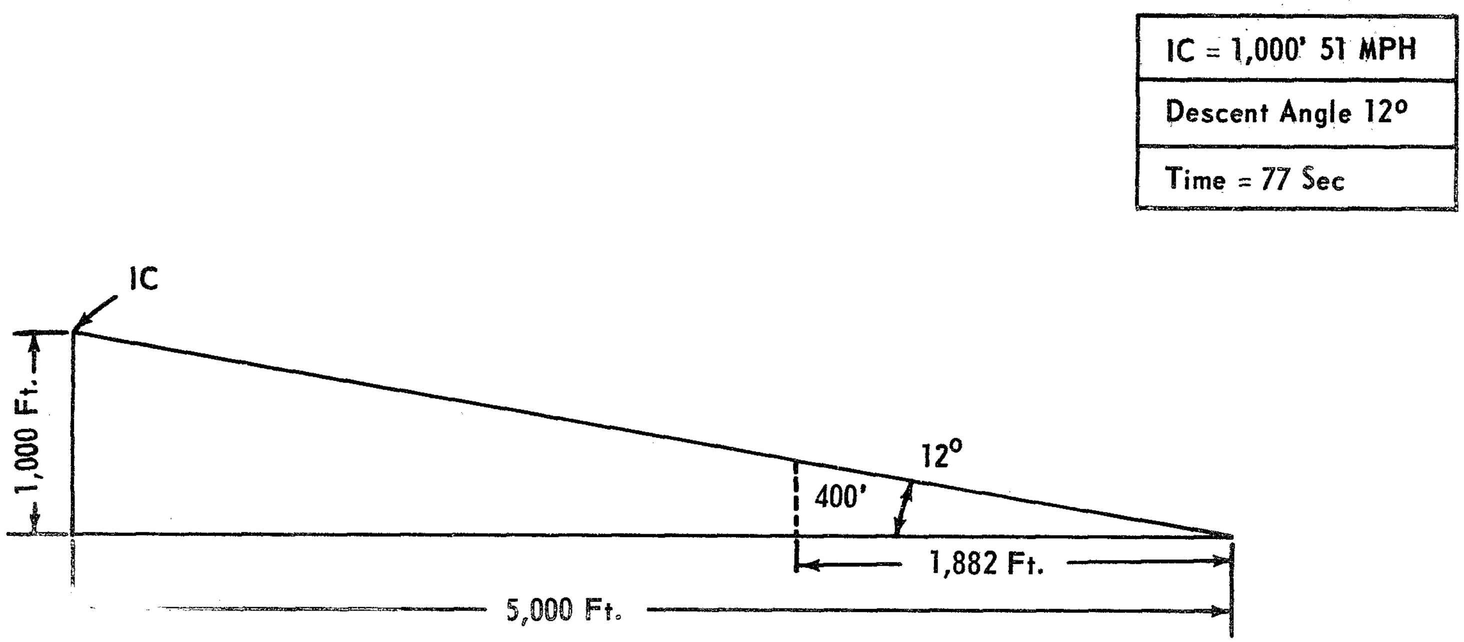

Figure 4 - Continued

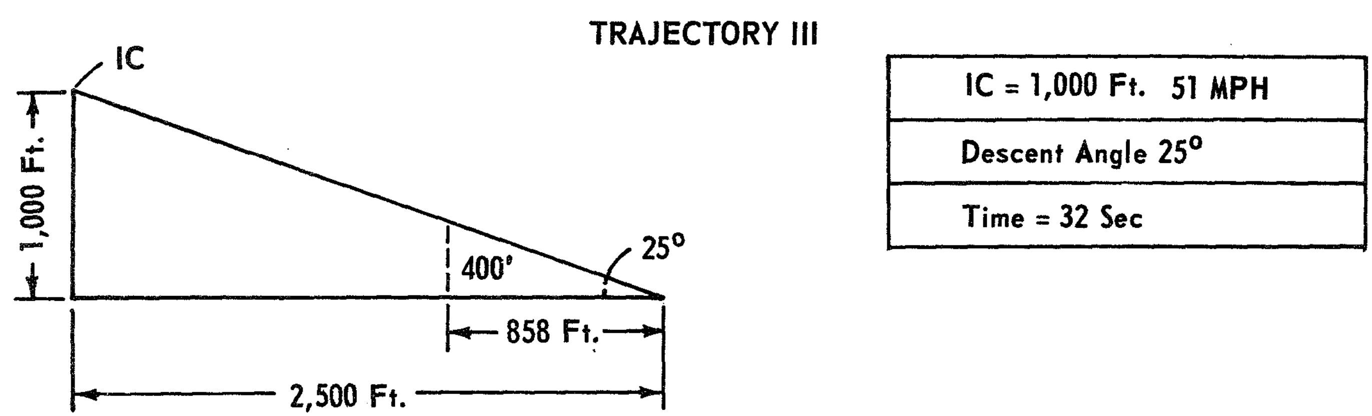

Figure 4.- Continued.

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TRAJECTORY IV

IC = 1,000 Ft.; 51 MPH
Descent Angle 12°
Descent to 400'
Level for 5 sec.
Commence descent to target
Descent Angle = 16°
Time = 100 Sec

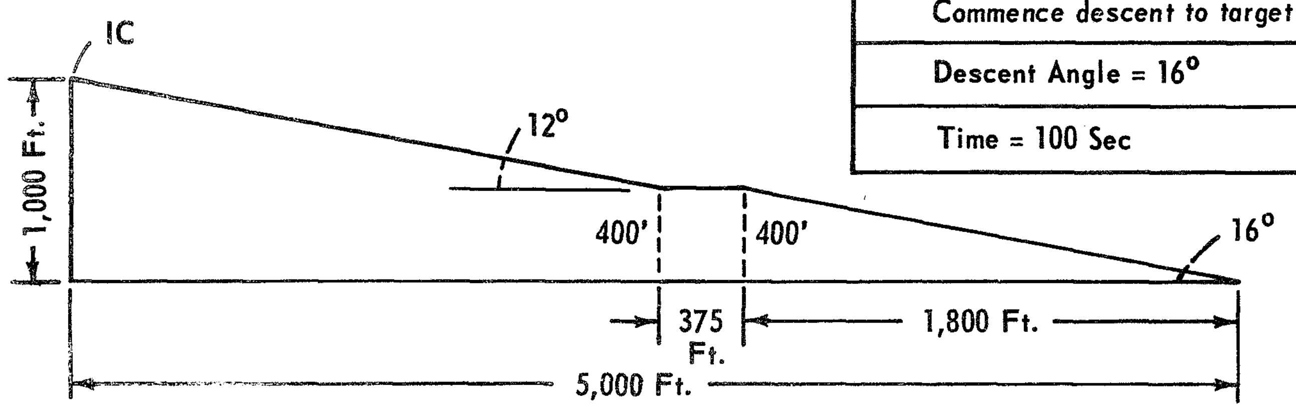

Figure 4 - Continued

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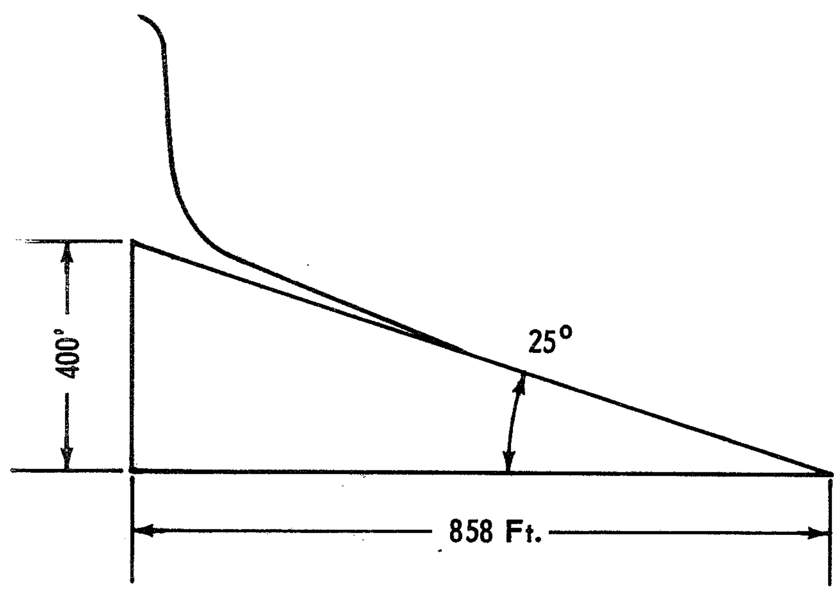
TRAJECTORY V



IC = 1,000 Ft., 51 MPH
Vertical Descent to 400'
Speed = As Required
Descent Angle 25°
Time 45 Sec

Figure 4 - Continued

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TRAJECTORY VI

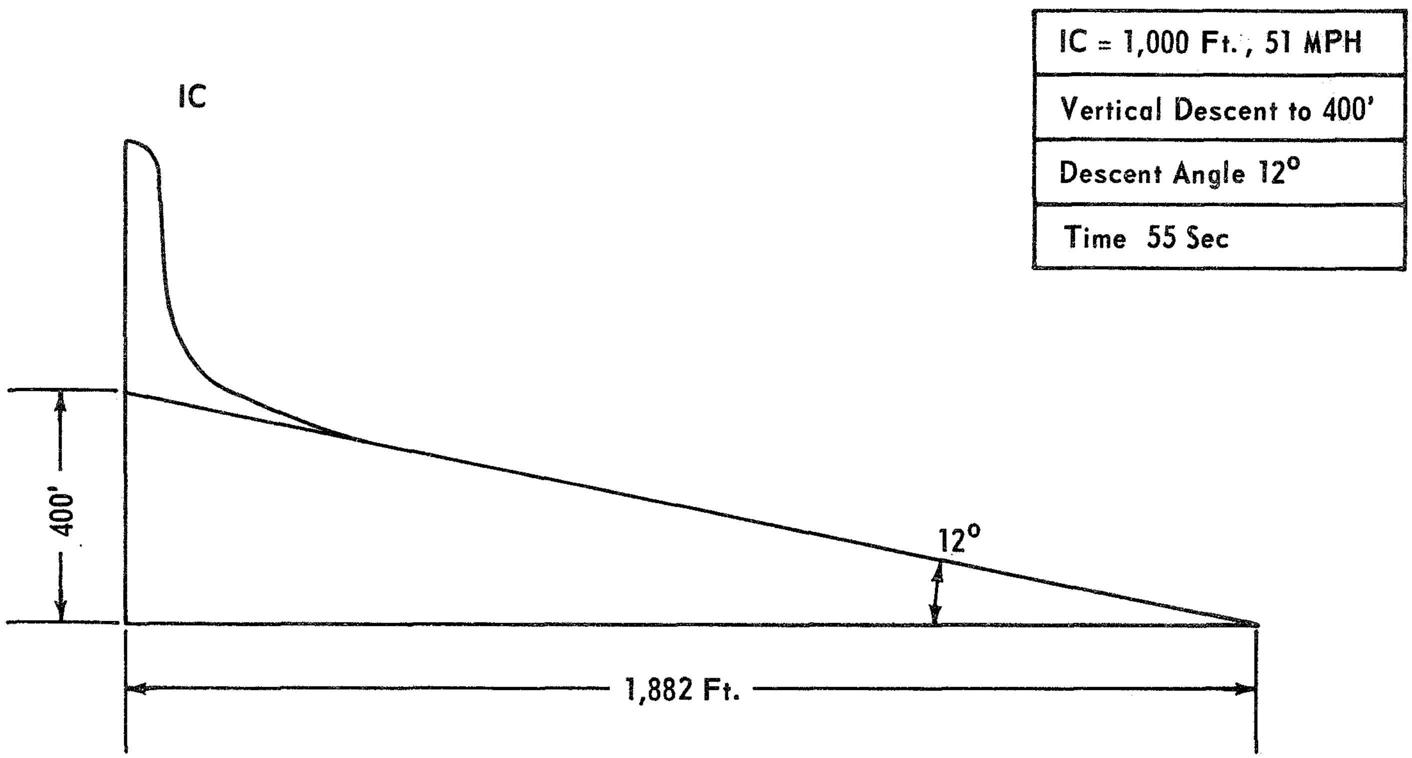

Figure 4 - Concluded

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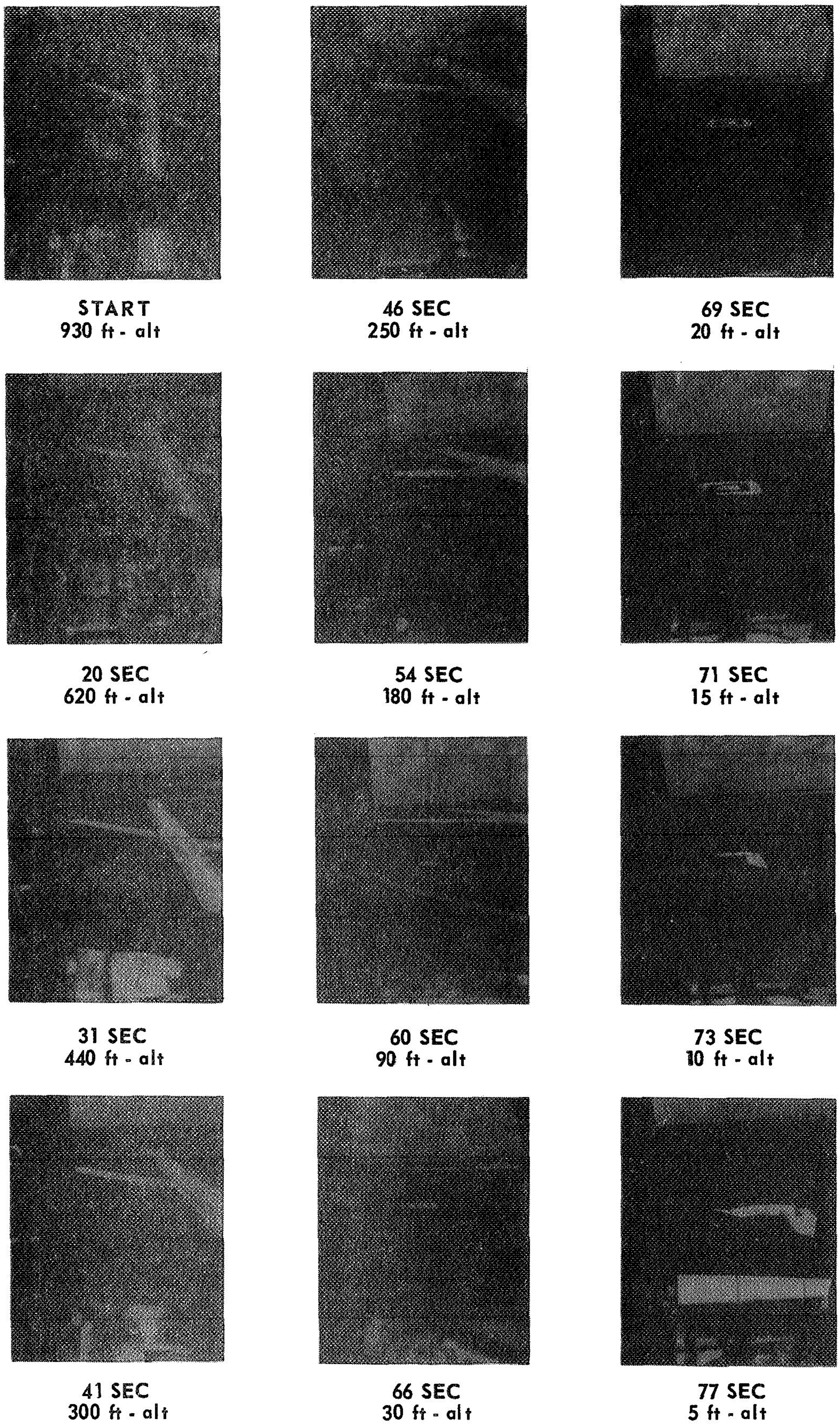

Figure 5 - Autorotation trajectory - showing upper window view of landing target under reduced illumination.